# INFLUENCE OF PASSENGER CAR AIR CONDITIONER SYSTEM THERMOSTAT LEVEL SETTING TO FUEL CONSUMPTION AND THERMAL COMFORT

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## ABSTRACT

Malaysia is a tropical country with very high temperature during the day. Car users in Malaysia need in car air-conditioning system because the weather is hot and humid all year. Passenger adjusts the thermostat level (temperature knob setting) position to regulate the cold air temperature supplied to the cabin. By adjusting the thermostat, it affects the vehicle fuel consumption. When thermostat level is set to the lowest setting, compressor need to be driven on a regular basis and this require power from the engine. With the use of engine power, fuel consumption will increase. Fuel prices are very unstable and can get very high thus the need to lower its consumption. The objective of this study is to measure fuel consumption of different thermostat level setting of the air conditioning system, in the case of stationary cars and without passengers and driver in it. The data in this study were taken in four different modes and the two levels of the selected fan speed. At the same time the cabin temperature is monitored by specific device, to record the temperature, relative humidity and $CO_2$. Fuel consumption was tested by filling 5 liters of petrol into the external tank. After one hour of testing, the total of fuel consumption can be calculated by measuring the amount of fuel remaining. At the end of the experiment, the most practical and suitable thermostat level setting will be propose based on the fuel consumption usage and according to the specifications of the appropriate level of comfort based on parameters such as temperature, relative humidity and $CO_2$. Besides saving on fuel, it is also in this mode that the condition of temperature and humidity in the car's cabin were found to be most comfortable. Recorded temperature is 25.83ºC, relative humidity 51.72% and $CO_2$ is 553 ppm. The selected mode is at mode 4 low blower fan speed. The fuel consumption in this mode is amounted 1220 litres.

## ABSTRAK

Malaysia merupakan sebuah negara tropika dengan suhu yang sangat tinggi pada waktu siang. Pengguna kereta di Malaysia memerlukan kereta sistem penghawa dingin kerana cuaca yang panas dan lembap sepanjang tahun. Penumpang perlu menyesuaikan kedudukan tahap termostat (melaras pusingan tombol suhu) untuk mengawal suhu udara sejuk yang dibekalkan ke kabin. Penyelarasan thermostat boleh menjejaskan penggunaan bahan api kenderaan. Apabila tahap termostat disetkan pada kedudukan suhu paling minimum, pemampat sentiasa bekerja dan kuasa dari enjin sentiasa digunakan. Kekerapan menggunakan kuasa enjin menyebabkan penggunaan bahan api akan meningkat. Harga minyak semasa adalah sangat tidak stabil dan boleh menjadi sangat tinggi pada sesuatu masa, maka mengurangkan penggunaan bahan api adalah perlu. Objektif kajian ini adalah untuk mengukur penggunaan bahan api dengan penetapan laras suhu yang berbeza pada sistem Penyaman udara, dalam keadaan kereta tak bergerak dan tanpa penumpang dan pemandu di dalamnya. Data dalam kajian ini dilaksanakan dengan memilih dua tahap kelajuan kipas dan  setiapnya ada empat kedudukan laras suhu yang berbeza. Pada masa yang sama suhu kabin turut dipantau oleh peranti tertentu untuk merekodkan suhu, kelembapan dan $CO_2$. Penggunaan bahan api diuji dengan mengisi 5 liter petrol ke dalam tangki luar. Selepas satu jam ujian dijalankan, jumlah penggunaan bahan api boleh dikira dengan mengukur jumlah baki bahan api. Pada akhir percubaan, tetapan laras suhu yang paling praktikal dan sesuai  telah dicadangkan berdasarkan penggunaan bahanapi dengan mengikut spesifikasi tahap keselesaan berdasarkan parameter seperti suhu, kelembapan dan $CO_2$ yang bersesuaian. Selain menjimatkan bahan api, kajian ini juga dapat menemui tahap laras suhu dengan keadaan suhu dan kelembapan di kabin adalah selesa. Suhu yang direkodkan adalah 25.83ºC, kelembapan 51.72% dan CO2 553 ppm. Kedudukan laras suhu yang telah dipilih adalah pada kedudukan kelajuan kipas rendah  pada kedudukan mod 4. Penggunaan bahan api dalam mod ini adalah berjumlah 1220 liter.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of study

Malaysian car users desperately need car air conditioning because of the hot and humid weather throughout the year. When the car users need comfort, the thermostat adjuster is set to low temperature level. This will force the air condition system to use more power and increase fuel consumption. As fuel price can get very high depends on demand, the need to minimize fuel usage is a must.

Comfort is very important in human life. Comfort is affected by temperature, relative humidity and $CO_2$. Thermostat function is to control the air conditioning system with turn off or turn on the compressor. When the compressor is turned off it can save fuel by reducing the engine power. When the compressor turned run, the engine power consumption will increase and also will increase fuel consumption.

The performance is recorded by different thermostat mode/level until for 1 hour duration. This test will be performed in the morning between 9.00a.m to 11.00a.m. The Malaysia Meteorological Service (MMS) has recorded for a ten-year period relatively uniform outdoor temperature pattern with an average temperature in a range between 23.7 °C to 31.3 °C with maximum temperature recorded as 36.9 °C throughout a day with average relative humidity between 67 % to 95 %. The temperature and humidity will be recorded by using the tool Model Telaire 7001. This studies is to minimize fuel consumption with selected suitable thermostat level in car air conditioning system. At the same time car drivers and passengers get comfortable.

## 1.2 Problem statement

The air conditioning system serves to comfort the driver and passengers in a car. To get the appropriate comfort the temperature and humidity should be at about 72 F (22ºC) to 80 F (26.67ºC) and 30-to 60% in the summer by *ANSI/ASHRAE Standard 55*. Temperature and humidity can be controlled using the thermostat.

Air conditioning system works by using four basic components, namely the compressor, condenser, metering devices and evaporator. The prime mover in this system is the compressor. The compressor is driven using engine power in the car. Compressor is controlled by adjusting the temperature on the thermostat. Lower temperature setting will required the compressor to at higher capacity and the addition of this workload affects car fuel consumption. So, to save energy consumption we need to control the use of the compressor by setting the thermostat at relevant temperature level with low fuel consumption while maintaining good car cabin thermal comfort.

## 1.3 Objectives of study

The objectives of this study are:

i. To measure fuel consumption regarding to thermostat level in car air-conditioning system.
ii. To suggest the most reasonable set point that achieves good balance between thermal comfort and fuel consumption.

## 1.4 Scopes of study

The scopes of this case study are as follows:

i. Sedan car approximately 3m$^3$ volume of size have used.
ii. Test are conducted around in the morning at 9.00a.m – 11.00a.m.
iii. Test vehicle is static (parking mode).
iv. 5 litres of fuel supplied to the external tank. Fuel consumption will be measured after 1 hour of experiment.
v. Test Instrument temperature and humidity with Telaire 7001.

## 1.5 Significant of study

Normally car users adjust the thermostat without taking into consideration of fuel consumption. When the thermostat level at lower temperature set point, this has been caused the compressor continues to operate and lead to increased energy use car fuel. At the same time the temperature in the car becomes too cold cause discomfort. The results from this study will provide a temperature adjustment that can reduce fuel consumption and at the same time maintain car cabin thermal comfort at acceptable level.

# CHAPTER 2

# LITERATURE REVIEW AND THEORY

## 2.1 Introduction

The use of car air conditioning system is for the comfort of the driver and passengers. The air conditioning system will create a comfortable environment to the control of temperature and humidity. However, energy consumption in air tends to increase fuel consumption. Energy consumption of unit tried to be reduced and became a major concern in the automotive industry. To address this issue have been made in various ways (Oh *et al.*, 2014). Among them is the study to be carried out this by making the controls on thermostat to minimize energy consumption of fuel. In the meantime the comfort in the vehicle is not ignored.

### 2.1.1 Car Air Conditioning System

Figure 2.1 is the air conditioning system is use in the car cabin. This system use to make comfort in the car cabin. This system controls the temperature, humidity and also air flow in the car cabin. Four basic components used in these systems namely compressor, expansion devices, condenser and evaporator. Figure 2.2 show the refrigerant in the car air conditioning system.

Air-conditioning stability and control are concepts concerned with the cabin indoor air quality and thermal comfort characteristics of an air-conditioning system. Therefore, inherent in the system are its dynamics and complexity. The control of ventilation and air-conditioning system is a difficult problem, because even the simplest air-conditioning models are multi-variable and nonlinear. Finally, these systems are influenced by multiple uncertain disturbances (Khayyam *et al.*, 2012).

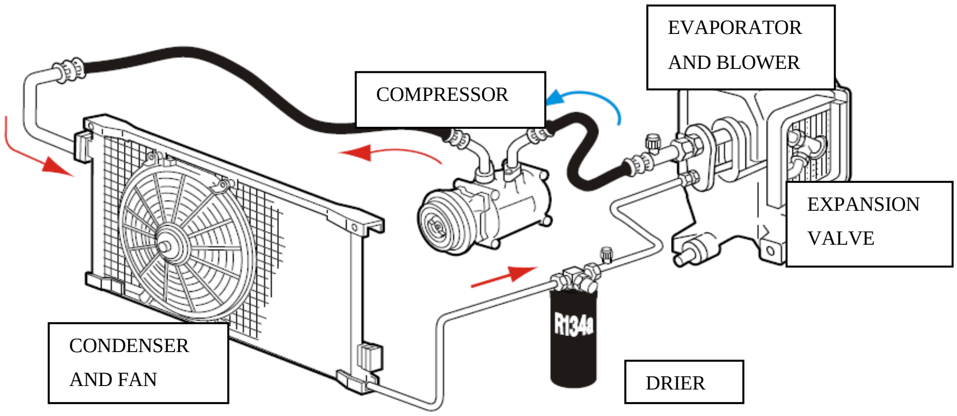


Figure 2.1: Car Air-conditioning System (*Ariazone - Automotive Air Conditioning Training Manual*, n.d.)

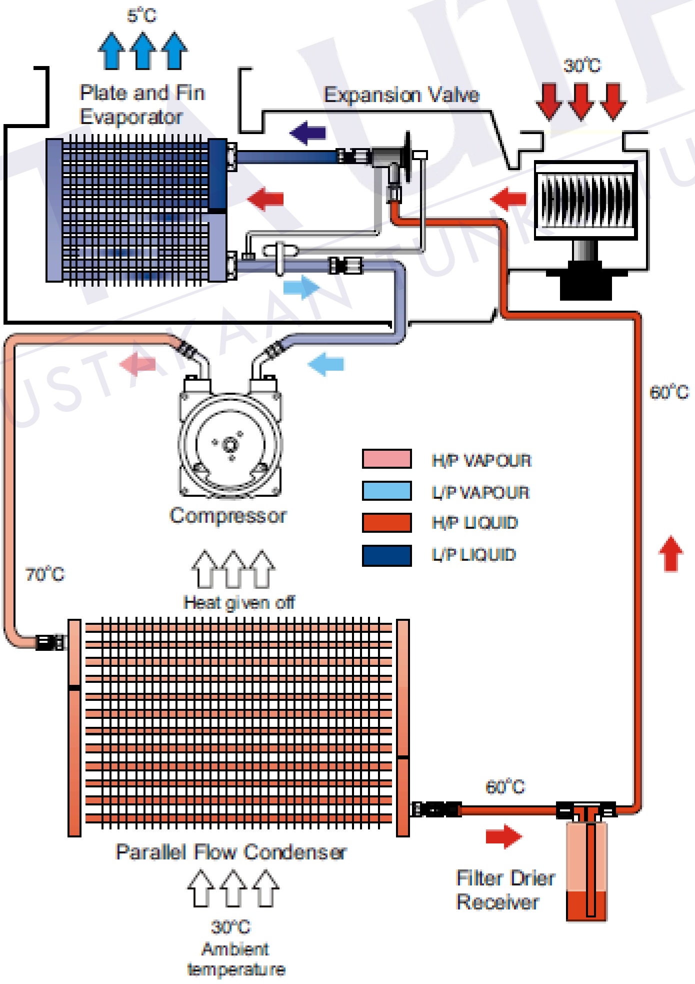


Figure 2.2: Car Air-conditioning System Refrigerant Flow (*Ariazone - Automotive Air Conditioning Training Manual*, n.d.)

#### 2.1.1.1 Compressor

Compressor serves to compress gas R134a with increasing temperature and pressure. The compressor receives gas from the evaporator is then sent to the condenser. Compressor must receive 100 % of the gas to be compressed. The compressor is located beside the car engine. This compressor is controlled by using a belt driven by the engine. The most common reasons for failure are lack of oil, pulley bearing wear, electromagnetic coil burn-out and lack of regular servicing.

#### 2.1.1.2 Condenser

The condenser type is use fin and tube. The function of the condenser is to reject heat. Heat is rejected using a fan and also natural air while the car is moving. Gas flowing inside the tubes in the condenser will slowly become liquid. Liquid 134a is still in a state of high pressure and temperature. This liquid will move to expansion devices. Condenser is usually located at the front of the car.

#### 2.1.1.3 Receiver Drier/Accumulator

Depending on the type of air conditioning system fitted, this item can be called a Receiver Drier or an Accumulator. (The Accumulator is fitted on the low pressure gas line of an air conditioning system between the Compressor and the Evaporator and is used in conjunction with an orifice tube). The Receiver Drier is fitted on the high pressure liquid line of an air conditioning system between the Condenser and Expansion Device. The Receiver Drier has two parts to it, the receiver and, of course, the drier. The receiver section holds the right amount of refrigerant required by the system to ensure correct operation and to supply a steady flow of liquid refrigerant to the Expansion Device. The drier section is responsible for removing moisture from the air conditioning system by means of a bag of desiccant which absorbs small quantities of moisture. This is a very important part of the air conditioning system and should be changed at least every two years or when the system is repaired. The most common reasons for failure is corrosion and desiccant deterioration which leads to severe system failure.

#### 2.1.1.4 Expansion Devices

The Expansion Device comes in many forms. It can be a brass internally or externally equalised valve, a block type valve or an orifice tube (the latter being part of an Accumulator type air conditioning system). Expansion Device's have an inlet and an outlet which separates the high side of the system from the low side. A small restriction in the valve allows only a small amount of refrigerant to pass through it into the evaporator, the amount of refrigerant passing through the valve depends on the Evaporator temperature. The most common reasons for failure are contamination, moisture and lack of regular servicing.

#### 2.1.1.5 Evaporator

As soon as the liquid pressure drops, the refrigerant begins to boil (R134A refrigerant boils at approximately -26 degrees centigrade). As it continues to boil the Evaporator absorbs the heat passing over its tubes and fins and as a result the air is cooled. Remember that heat is being removed from the warm air and cold air is not being created. The compressor, on its suction side, removes the low pressure vapour from the Evaporator and the cycle starts all over again. The most common reasons for failure are corrosion, weak spots in construction and lack of regular servicing.

## 2.2 Human Comfort

Human thermal comfort is defined by The American Society of Heating Refrigeration and Air Conditioning Engineers ASHRAE, as the state of mind that expresses satisfaction with the surrounding environment (Oleesen & Brager, 2004). Comfort in car cabin most important when driving in long journey.

Thermal comfort of humans corresponds to a simple but permanent motivation that compels him to seek certain climatic situations, to maintain some of them, and to judge them in terms of pleasure or inconvenience. It becomes one of the significant criteria of selection during the acquisition of a car (Mezrhab & Bouzidi, 2006)

A simple thermal comfort model determined the percentage of time that a driver used the air conditioning (Johnson, 2002). The thermal-comfort link was based on the premise that if a person were dissatisfied with the thermal environment, they would turn on the air conditioning. The thermal comfort results were then combined with statistics on when people drive, where they live, and how far they drive in a year. Finally, vehicle simulations determined the fuel use penalty of using the air conditioning in cars and trucks. ‘

Thermal comfort depends on thinking someone in expressing a sense of satisfaction with the thermal environment. Because there are large variations in psychology from person to person, it is difficult to reconcile the comfort at the same rate in a space. Each person will not be similar in feel comfortable environment (Alahmer *et al.*, 2011). But fixing the level of temperature and humidity where most people feel comfortable there needs to be. However, extensive laboratory and field data have been collected that provide the necessary statistical data to define conditions that a specified percentage of occupants will find thermally comfortable. Based on ASHRAE standard 55, good thermal comfort reached whereby eighty percent or more people in the room feel comfortable. ‘Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment’ (Hall 2011).

Predict thermal comfort in the vehicle is very complex because of the behaviour during a fast cool-down after a hot soak, and non-uniform thermal environment related with a very limited to a small area air velocity and temperature distribution , solar flux and heat flux of radiation around the inner surface. Analyzer for temperature and velocity distribution in the passenger compartment, coupled with the forecast thermal comfort can guide the direction of design in the early stages of vehicle development process (Han & Huang, 2005).

The car cabin temperature environment is complex, cannot be assessed with temperatures only because it will change from time to time. Air temperature, relative humidity, air velocity, environment radiation are important parameters that affect thermal comfort (Farzaneh & Tootoonchi, 2008).

## 2.3 Temperature and Relative Humidity

Air temperature is a measure of how hot or cold the air is. It is the most commonly measured weather parameter. More specifically, temperature describes the kinetic energy, or energy of motion, of the gases that make up air. As gas molecules move more quickly, air temperature increases. ASHRAE Standard 55 prescribes 3ºC for the vertical air temperature difference between head and ankle level (*ANSI/ASHRAE Standard 55*, 2010).

Neacsu *et al.* study the temperature-time dependence; transfer data from the acquisition to the computer system was made every 60 seconds. Air conditioning system has been used in both the situation and the parameters were the same (temperature, flow, type). Value for four cases in this experiment are presented in Table 2.1, considering between the hours 9:00-10:00 for Case 1 and between 12:00-13:00 for Case 2 ( Neacsu *et al*., 2009).

Table 2.1: Temperature values measured experimentally (Neacsu et al., 2009)

| Time[s] | Temperature Case 1 [°C] | | Temperature Case 2 [°C] | |
|---|---|---|---|---|
| | AC ON | ACC OFF | ACC ON | ACC OFF |
| 0 | 29.0 | 29.0 | 29.0 | 29.0 |
| 300 | 25.8 | 32.2 | 26.3 | 34.1 |
| 600 | 24.6 | 34.2 | 25.8 | 37.2 |
| 900 | 23.8 | 35.6 | 24.6 | 39.4 |
| 1200 | 22.8 | 36.8 | 23.7 | 40.8 |
| 1500 | 22.3 | 37.5 | 23.4 | 42.0 |
| 1800 | 22.2 | 38.3 | 23.2 | 42.9 |
| 2100 | 22.0 | 39.1 | 23.0 | 43.8 |
| 2400 | 21.8 | 39.9 | 22.9 | 44.2 |
| 2700 | 21.6 | 40.5 | 22.8 | 44.7 |
| 3000 | 21.6 | 41.3 | 22.7 | 45.0 |
| 3300 | 21.5 | 42.0 | 22.6 | 45.7 |
| 3600 | 21.4 | 42.6 | 22.6 | 46.0 |

Relative humidity is the amount of water vapour present in air expressed as a percentage of the amount needed for saturation at the same temperature. Relative humidity is measured in only one place inside the vehicle because the pressure of the water vapour is uniform in the entire vehicle. The human body is sensitive to air humidity changes. The thermal comfort sensation is optimal when the relative humidity value is about 50% (Musat & Helerea, 2009). The recommended temperature and humidity at Figure 2.3.

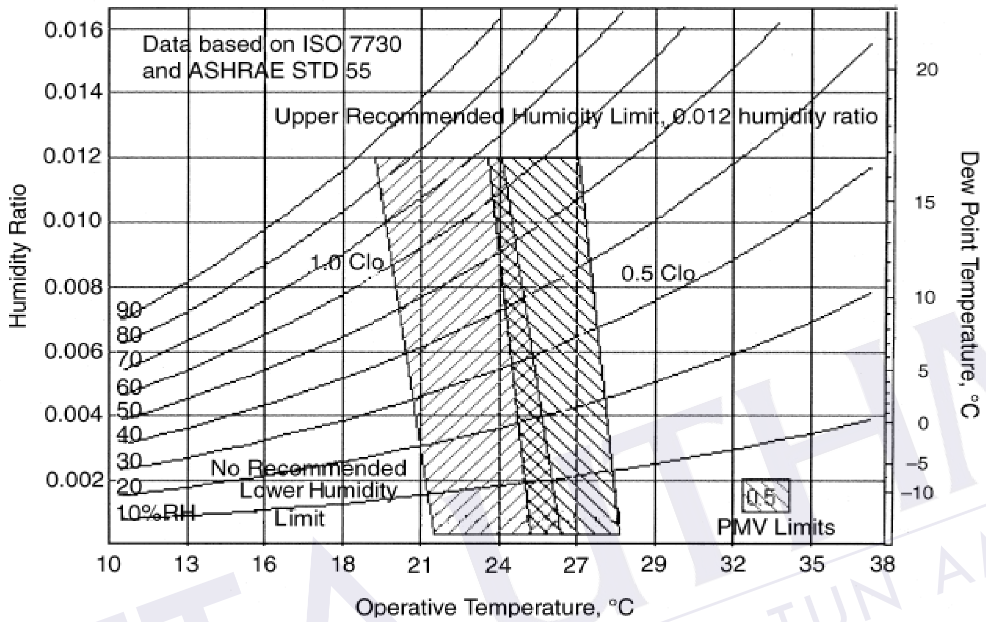


Figure 2.3: Comfort range temperature and humidity (*ANSI/ASHRAE Standard 55*, 2010).

## 2.4 Air Speed

Precise relationships between increased air speed and improved comfort have not been established. However, this standard allows elevated air speed to be used to increase the maximum temperature for acceptability if the affected occupants are able to control the air speed (*ANSI/ASHRAE Standard 55*, 2010). The amount that the temperature may be increased with air speed is shown in Figure 2.4.

To promote sustainable AC design, the direction should be increasing the air speed rather than reducing the air temperature and humidity to achieve the same level of comfort sensation. Energy saving would be greatly enhanced if the temperature and the humidity is set to the neutral operative temperature 27.5°C and 60% RH, the air speed being 0.36m/s with ≤ 1.2 activity level for sedentary working environment and light clothing insulation of 0.5 clo. Provisions should be there for locally adjustable airflow devices such as miniature fans in meeting individual preferences (Yau *et al*., 2011).

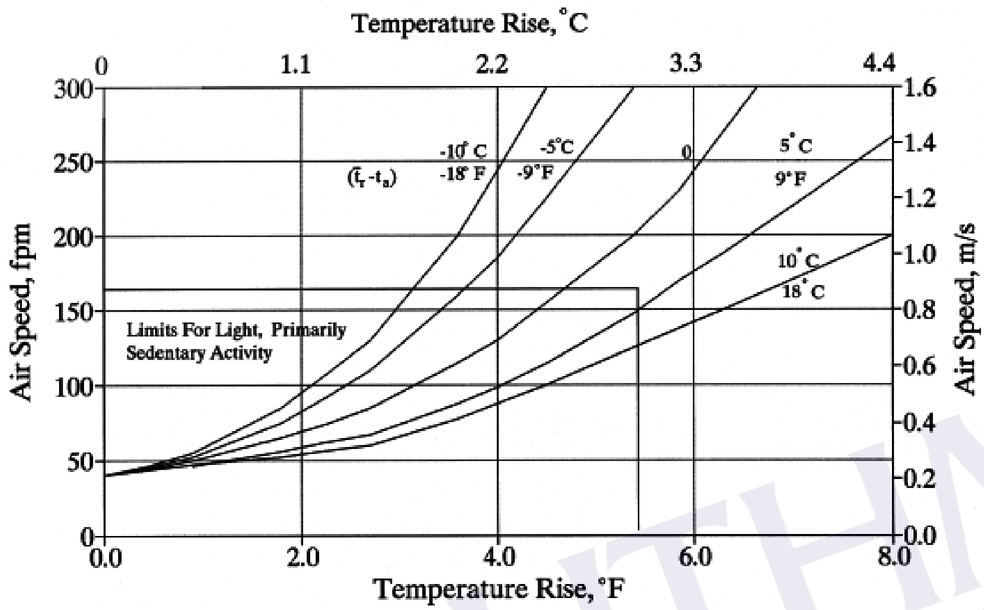


Figure 2.4: Air speed required to offset increased Temperature (*ANSI/ASHRAE Standard 55*, 2010).

## 2.5 Fuel Consumption

The use of air conditioning systems will increase fuel consumption significantly. In the automotive industry, fuel reduction can be done by controlling the use of air conditioning systems mainly compressor. Automotive industry today has applied a few modifications to control air conditioning compressors (Tenberge & Baumgart, 2010). This system can affect the fuel consumption because the compressor engages with the engine. This will result in increased load on the engine and fuel consumption also increases. The effect is larger with higher fuel economy vehicles (Johnson, 2002).

The mechanical compressor of the air conditioning system could increase the fuel consumption of the vehicle by 12-17% for subcompact to mid-size vehicles (Khayyam *et al*, 2011)

## 2.6 Carbon Dioxide, $CO_2$

1000 ppm would be regarded the upper limit of healthy condition, the equipment limitation should be acceptable in determining on the quality of air in the compartment Mohd Sahril Mohd Fouzi et al, 2014.

# CHAPTER 3

# METHODOLOGY

## 3.1 Overall Project Flow

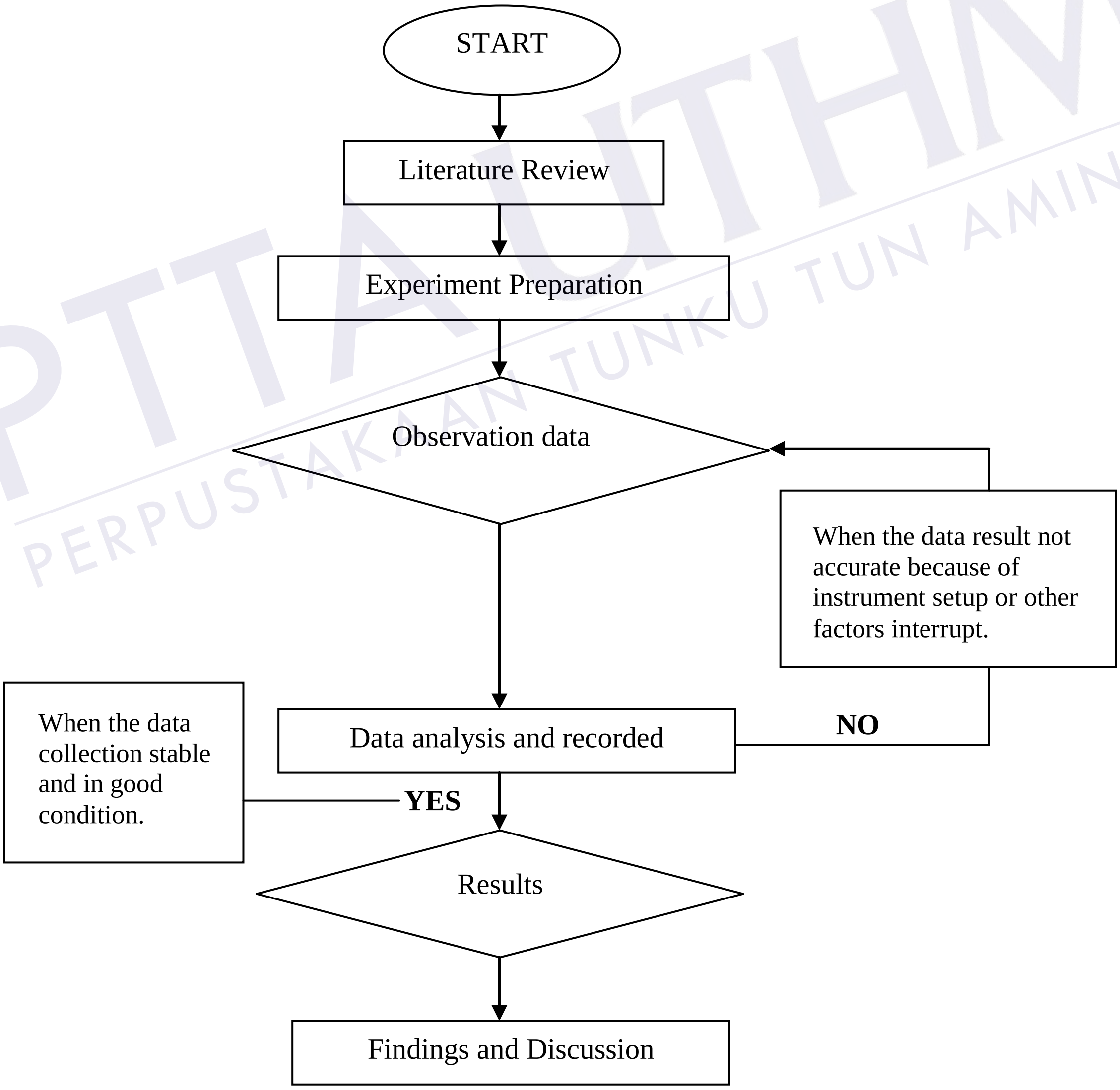


Figure 3.1: Flow chart methodology

## 3.2 Experiment Parameter

This experiment study blower fan speed and thermostat level setting affect to fuel consumption. Also, parameters that influence transient thermal comfort during the experiment period were also recorded. The experiments included conditions of 2 blower fan speed, and 4 thermostat level setting. Each testing repeated in the same manner with different setting.

## 3.3 Experiment Procedures

This research started of with the fabrication of the external fuel tank, Figure 3.2. It is made of iron plates and upon completion it has the capacity to store 10 liter of fuel. The need for an external tank is to enable a more accurate observation and measure the rate of fuel consumed.

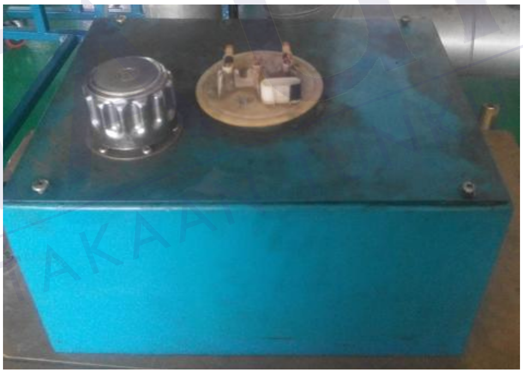

Figure 3.2: External fuel tank

A Proton Persona car as in Figure 3.3 is used to collect all the data needed for this study. The Proton Persona is a 2009 model with 1.6L high line, as shown in Figure 3.4. For the purpose of this study, the car's usage is assumed at good conditions and using tinted film on the front side windows at 70% of light in, side windows and rear windows at 50% light in.

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